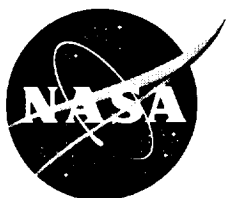


NASA/TP—1999-209577



## Lightweight Seat Lever Operation Characteristics

*Sudhakar L. Rajulu, Ph.D.*  
*Lockheed Martin*  
*Houston, Texas*

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September 1999

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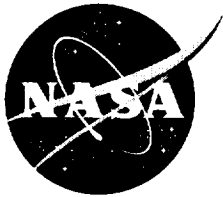
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NASA/TP—1999-209577



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# Contents

Contents.....	iii
Lightweight Seat Lever Operation Characteristics.....	1
Objective .....	1
Background .....	2
Method .....	2
Subjects .....	4
Experimental Design .....	5
Experimental Procedure .....	6
Results .....	7
Unpressurized Test Results .....	8
Pressurized Test Results.....	9
Learning Effects .....	9
Conclusion.....	11
Limitations .....	12
Recommendations .....	12
Reference.....	12
Appendix A, Maximum Static Exertion Data per Subject per Trial .....	13

## Figures

Figure 1. Force link and the cable setup to measure static push force. ....	3
Figure 2. Experiment setup showing the backrest controller connected to the load cell cable. ....	4
Figure 3. Subject performing static push exertion on inertia control knob. ....	5
Figure 4. Subject performing static push exertion on back seat control knob. ....	6
Figure 5. Even with an unpressurized suit, this subject was barely able to grasp the backrest knob. ....	8
Figure 6. This subject was unable to reach the backrest knob when wearing the pressurized ACE suit. ....	10

## Tables

Table 1. Averaged Peak Static Force Data .....	7
Table 2. Averaged Peak Static Force Data Under Pressurized and Unpressurized Condition .....	9
Table 3. Averaged Peak Static Force Data on Day 1 and Day 2.....	10
Table 4. Percentile Classification of the Two Astronauts Who Participated With the Pressurized ACE Suit Based on Different Anthropometric Measurement.....	12



## **Lightweight Seat Lever Operation Characteristics**

During a Shuttle flight in the early part of 1999, one of the crew members was unable to operate the backrest lever for the lightweight seat in microgravity. It is essential that the crewmembers are able to adjust this backrest lever, which is tilted forward 2 deg from vertical during launch and then moved backward to 10 deg aft of vertical upon reaching orbit. This adjustment is needed to cushion the crew members during an inadvertent crash landing situation. The original Shuttle seats, which had seat controls located on the front left and right sides of the seat, were replaced recently with the new lightweight seats. The controls for these new seats were moved to the right side with one control at the front and the other at the back. While it was uncertain whether the problem encountered was unique to that crewmember or not, it was clear to the personnel responsible for maintaining the Shuttle seats that not knowing the cause of the problem posed a safety concern for NASA. Hence Johnson Space Center's Anthropometry and Biomechanics Facility (ABF) was requested to perform an evaluation of the seat controls and provide NASA with appropriate recommendations on whether the seat lever positions and operations should be modified.

The ABF designed an experiment to investigate the amount of pull force exerted by subjects, wearing an unpressurized or pressurized crew launch/escape suit, when controls were placed in the front and back (on the right side) of the lightweight seat. Single-axis load cells were attached to the seat levers, which measured the maximum static pull forces that were exerted by the subjects. Twelve subjects, six male and six female, participated in this study. Each subject was asked to perform the pull test at least three times for each combination of lever position and suit pressure conditions.

The results from this study showed that, as a whole (or in general), the subjects were able to pull on the lever at the back position with only about half the amount of force that they were able to exert on the lever at the front position. In addition, the results also showed that subjects wearing the pressurized suit were unable to reach the seat lever when it was located at the back. Furthermore, the pull forces on the front lever diminished about 50% when subjects wore the pressurized suits. Based on these results from this study, it was recommended to NASA that the levers should not be located in the back position. In addition, further investigation is needed to determine whether the levers at the front of the seat could be modified or adjusted to increase the leverage for crewmembers wearing pressurized launch/escape suits.

### **Objective**

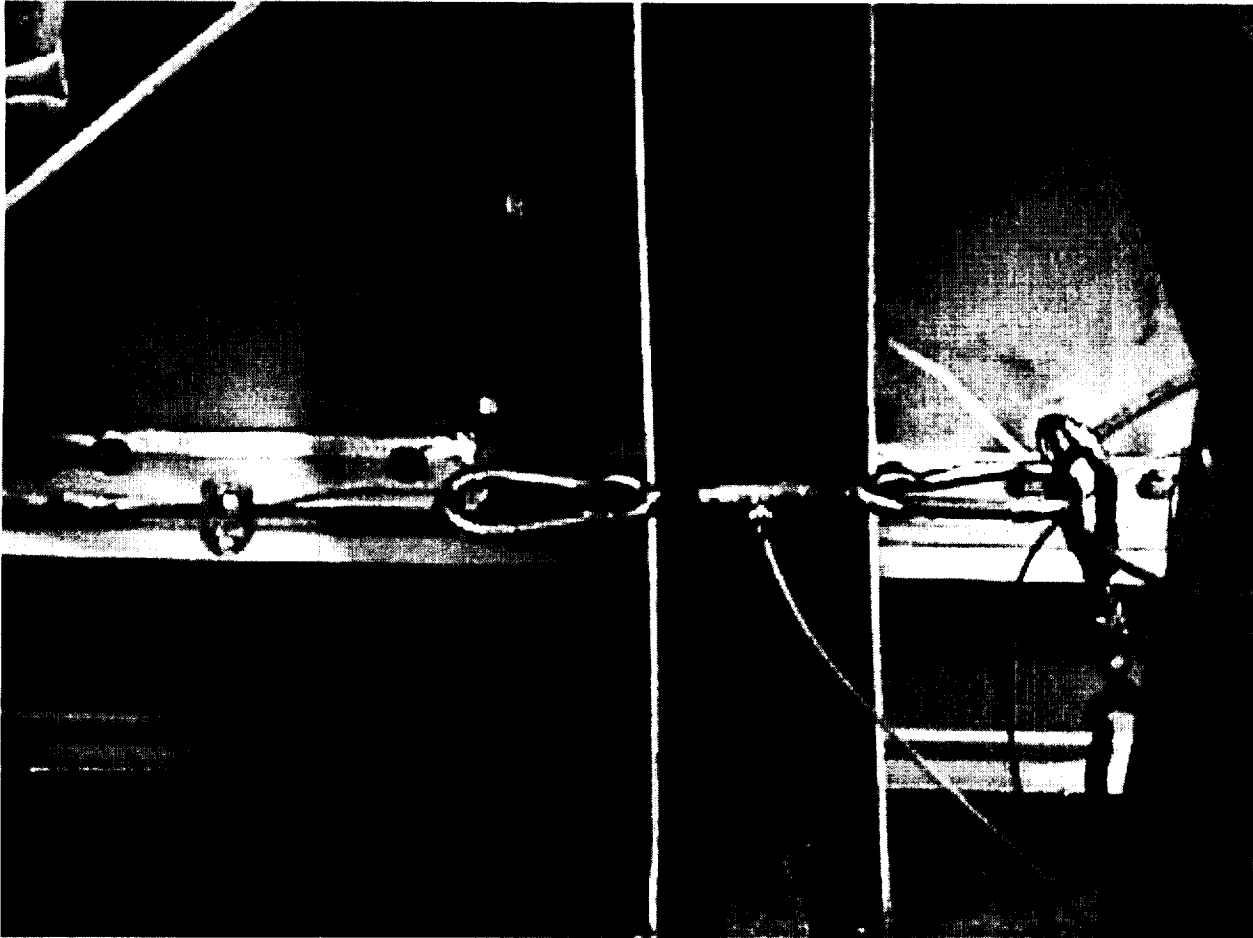
The primary objective of this test was to determine the maximum static forces that a person would be able to exert on the backrest and the inertia levers of the lightweight (LW) seats.

## **Background**

A concern was raised during a recent Shuttle flight that a crew member was unable to operate the backrest lever in 0-g. During liftoff the backrest angle is tilted forward to an angle of 88 deg (2 deg forward of vertical) and during re-entry the backrest angle is tilted backwards to an angle of 100 deg (10 deg aft of vertical). The backrest lever is located at the right-hand side close to where the backrest meets the seat pan and the inertia lever is located just below the seat pan near a person's right knee. The NASA and Boeing engineers were unsure whether the current location of the backrest lever required a crew member to overexert himself to operate it. They were hoping to alleviate this concern by modifying the seat controller positions in case the current arrangement may cause inconvenience to the crew member. One proposal was to move the backrest lever from the back to the front where the inertia lever is currently located and move the inertia lever to the left. Hence the purpose of this test was to determine whether the backrest lever should be kept at its current position or to move it to the front of the seat.

## **Method**

An experiment was set up in the ABF to measure the maximum static forces that a person would exert at a seat lever knob at two positions. One position was at the back where the backrest lever is currently located and the other one was at the front where the inertia lever is currently located. The lightweight seat was fastened to the base of an L-shaped test stand. The seat was positioned such that it was facing the wall of the test stand. We used a single-axis load cell connected to a heavy-duty cable to measure the push force exerted by the subjects. In order to accommodate the cable around the knob without severely affecting the subject's grasping ability, a replica of the knob was made with a long screw in the middle. An aluminum link was firmly fastened to the bottom of the knob with the help of the screw. One end of the cable was looped around a hole at the end of the link away from the knob. The other end of the cable was firmly wrapped around an I-beam of the test stand. The cable was cut in the middle to connect it to the load cell along with a turnbuckle. The turnbuckle was used to tighten the cable sufficient enough to prevent the normal sliding motion of the control lever. Each control knob was provided with its own cable and a load cell. Figures 1 and 2 show the load cell and the test setup.



**Figure 1. Force link and the cable setup to measure static push force.**



**Figure 2.** Experiment setup showing the backrest controller connected to the load cell cable.

## **Subjects**

Twelve subjects, six males and six females, participated in this test. Two male astronauts and three female astronauts were among the twelve subjects. The subject pool also included a short female of Asian heritage.

## Experimental Design

The test involved measuring the maximum amount of static force a person can exert at the knob at two different locations (backrest and inertia control lever positions). All subjects were tested while wearing the unpressurized ACES (advanced crew escape suit) condition. Two of the crew members were also tested with the ACES pressurized. No seat cushion padding was used for this test. It was omitted since some crew members prefer to use it while others do not use it. Often smaller crew members don't use it since it limits their arm reach.

Figures 3 and 4 show the subject performing static exertion tasks on the two control knobs.



**Figure 3. Subject performing static push exertion on inertia control knob.**



**Figure 4. Subject performing static push exertion on back seat control knob.**

### **Experimental Procedure**

Each subject was asked to wear the inner garments before donning the ACES and the life preserver. The test subject was shown how the instrumentation was set up to gather her maximum push forces. After the subject was seated and fastened with the seat belts, she was asked to locate the control knobs with the right hand. The subject was assisted only when it was difficult for her to find the knob. Then the subject was instructed to grab the knob and push it towards the backrest as hard as she could. After the subject exerted her maximum force a few times, the experiment was repeated with the control knob moved to the next position.

Based on one or more crew members' suggestions that it would be more realistic to test under a pressurized condition than otherwise, two astronauts (1 male and 1 female) were also asked to perform the test under pressurized condition.

The ACES was pressurized to about 3.2 psi and tests were repeated as explained earlier. Even though they had already performed the unpressurized test condition on previous days, they were asked to repeat the unpressurized test along with the pressurized test. This was done primarily to eliminate any concern that may arise when the effect of pressurization on performance is determined.

## Results

The maximum static exertion data for each subject for each trial are included in Appendix A. Table 1 shows the averaged peak force exerted by the subjects at each of the controls, as well as the ratio of exerted force at the backrest knob to the exerted force at the inertia knob. (Note: averaged peak data for a subject were obtained by averaging the trial data. Ratio is obtained by dividing the backrest force by inertia lever force. For example, a ratio of 0.90 means that the backrest force is equivalent to 90% of inertia lever force.)

**Table 1. Averaged Peak Static Force Data**

Male Subjects				Female Subjects			
ID	Inertia Lever Force (lb)	Backrest Lever Force (lb)	Ratio	ID	Inertia Lever Force (lb)	Backrest Lever Force (lb)	Ratio
1	33.30	19.96	0.60	2	4.59	4.14	0.90
3	47.22	27.46	0.58	5	6.62	4.07	0.61
4	42.43	16.36	0.39	5*	9.78	4.58	0.47
4*	67.83	13.99	0.21	7	8.43	6.77	0.80
6	32.58	31.25	0.96	8	40.63	25.20	0.62
9	19.58	8.78	0.45	10	6.26	3.35	0.53
11	37.57	26.45	0.70	12	42.67	17.68	0.41
<b>Group Averaged Data</b>							
	40.07	20.61	0.51		17.00	9.40	0.55

(\* Means that the subject repeated the test on a second day)

## Unpressurized Test Results

As can be seen in Table 1, the force exertion varied considerably for both positions. As a group, the ratio of backrest to inertia lever force exertions was around 0.51 (males) to 0.55 (females). This suggests that the subjects' capability to exert a push force was diminished 50% when the control knob is located at the back position. However, there were some exceptions to this case. For instance, one male subject (ID= 6), and two female subjects (ID= 2 and 7) had very similar force capabilities at both knob positions. Unlike their male counterpart, these two female subjects did not exhibit a strong force exertion capability. A comparison of the group's data also showed that females had about 50% of the males' strength. This corresponds well with other strength data that the ABF had gathered in the past. The smallest force observed was about 3.35 lb for females and about 8.8 lb for males. It is unclear whether such low levels of force capabilities would be adequate to activate these levers under any operational condition.

Finally, with the exception of one female subject (Figure 5), all of the subjects were able to reach the knob and exert push forces at the two knob locations. However, a majority of the subjects (mostly females and one male) had difficulties finding the backrest knob.



**Figure 5.** Even with an unpressurized suit, this subject was barely able to grasp the backrest knob.

## Pressurized Test Results

Table 2 shows the effect of pressurization on these two subjects' exertion capabilities. No data were taken for the backrest control knob since both subjects were unable to reach and grab that knob (Figure 6). It can be seen from the data that both subjects were able to exhibit only about 40% of their unpressurized strengths for the inertia control knob. Since the tests did not involve a sufficient number of subjects, it's hard to generalize the comparative evaluation. However, from a conservative point of view, it does raise the question of a weaker person's capability to operate the levers while wearing a pressurized suit and life preserver.

**Table 2. Averaged Peak Static Force Data Under Pressurized and Unpressurized Condition**

Male Subjects				Female Subjects			
ID	Inertia Lever Force (lb)	Backrest Lever Force (lb)	Ratio	ID	Inertia Lever Force (lb)	Backrest Lever Force (lb)	Ratio
4(U)	67.83	13.99	0.21	5(U)	9.78	4.58	0.47
4(P)	29.20	No Data		5(P)	3.75	No Data	
P/U	0.43			P/U	0.38		

(U = Unpressurized and P = Pressurized. P/U represents the ratio of pressurized to unpressurized test.)

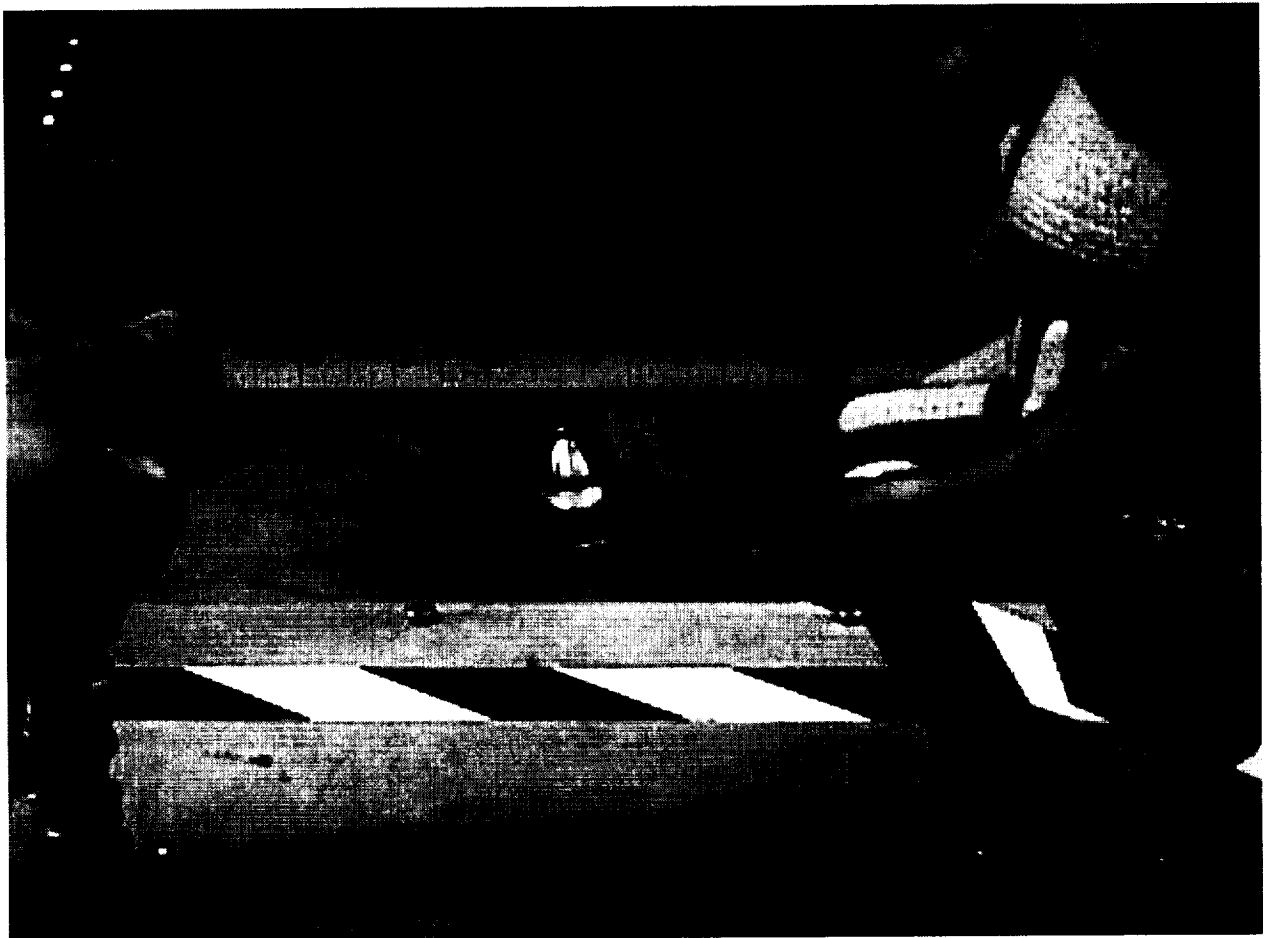
## Learning Effects

Table 3 shows the data taken from two subjects on two different days. The data clearly show that the subjects were able to increase their exertion by about 50% more from day 1 to day 2 for inertia lever knob position. For the backrest lever, the female subject was able to improve her exertion by 13% whereas the male subject's strength dropped by about 14%. Regardless of their marginal drop in their ability at pushing the backrest knob, there is definitely a learning effect from day1 to day2.

**Table 3. Averaged Peak Static Force Data on Day 1 and Day 2**

Male Subjects				Female Subjects			
ID	Inertia Lever Force (lb)	Backrest Lever Force (lb)	Ratio	ID	Inertia Lever Force (lb)	Backrest Lever Force (lb)	Ratio
4(D1)	42.43	16.36	0.39	5(D1)	6.62	4.07	0.61
4(D2)	67.83	13.99	0.21	5(D2)	9.78	4.58	0.47
D2/D1	1.60	0.86	-	D2/D1	1.48	1.13	-

(D1= day 1 and D2 = day 2; D2/D1 represents the ratio of day 2 exertion to day 1 exertion)



**Figure 6. This subject was unable to reach the backrest knob when wearing the pressurized ACE suit.**

## Conclusion

The data from this test show that the crew members will have difficulty accessing and exerting an adequate force on the backrest control knob at its current location. This is understandable since the crew members will have to rotate their shoulders inwardly and turn their palm towards their back to grab the knob and then push. Biomechanically, this is not a good position for the hand to exert a push force. Additionally, an inward rotation of shoulder also diminishes the ability of a person to use the hand effectively (Chaffin and Andersson, 1994). Limited data on pressurized suit condition also suggest that there is a possibility that the crew members will have reduced push force exertion capabilities under a pressurized suit and life preserver situation.

The smallest push force observed during this test was about 3.35 lb at the backrest knob position. It's not clear whether such a weak force capability would be sufficient enough to activate a lever situated at the back. Even with the knob located close to the knee, the smallest force from the subject pool was about 6.26 lb. Biomechanically, it is possible to increase the force exertion capabilities by increasing the surface area of the control knob. In other words, a larger control knob or a cylindrical rod would enable even a weaker person to have better grasp and force exertion capabilities.

The most comfortable position for the hand to perform a seated push type of task is one in which the hand is positioned with its palm down and located somewhere between elbow height and thigh height. The inertia controller knob is located in that region; hence, it is easy for the crew members to exert a push force adequately and comfortably. It should be noted however, that with the provision of cushion pads and pressurization, shorter female and male crew members would be elevated further away from the bottom of the seat pan. If this happens, those crew members might encounter problems while trying to reach the control knob located near the edge of the seat pan.

Even though this test did not anticipate the issue of reach capabilities of the crew members, the pressurized test showed that it would be an issue when the suit is pressurized. Since this test involved only two subjects, it's difficult to generalize the issue. However, none of the pressurized test subjects were close to a 5<sup>th</sup> percentile group (Table 4). For instance, their arm lengths represented a 55<sup>th</sup> percentile male and a 30<sup>th</sup> percentile female. Hence, the test raises the concern whether or not all crew members can reach the backrest control knob at its current position.

**Table 4. Percentile Classification of the Two Astronauts Who Participated With the Pressurized ACE Suit Based on Different Anthropometric Measurement**

ID	Sex	Standing Height	Sitting Height	Trunk Height	Arm Length
4	Male	30 <sup>th</sup>	45 <sup>th</sup>	60 <sup>th</sup>	55 <sup>th</sup>
5	Male	10 <sup>th</sup>	15 <sup>th</sup>	20 <sup>th</sup>	30 <sup>th</sup>

## **Limitations**

There were certain limitations associated with this test. First, the test did not investigate the exertion capabilities with the backrest resting on the floor (simulating the launch condition). An additional test with the backrest in launch position could have been useful to substantiate the results. Second, there is definitely a learning effect as seen from the data of the two subjects who repeated the test. However, it is unlikely that further training could improve a person's push capabilities considerably at the backrest lever. Third, the test did not have a sufficient number of subjects to justify the comparison of the pressurized test results to those of the unpressurized test. Yet, it can be seen from the above table that a person has to exhibit at least two anthropometric characteristics (a smaller trunk height with long arms) so that he/she may be able to reach the backrest lever. Fourth, even though this study has shown that all subjects were able to access the inertia lever, it is still possible that some of these subjects/crew members might still be unable to reach a lever in front under a pressurized suit condition.

Finally, no statistical analyses could be performed to contrast the difference between pressurized and unpressurized test conditions (due to an insufficient number of test subjects); hence generality of the data cannot be made with statistical confidence.

## **Recommendations**

If the designers were unable to move the backrest lever to the front due to technical difficulties, then it is necessary to perform a gap analysis to determine which crew member(s) will be affected. Then they should be given an alternative arrangement to operate the lever when the need arises.

If the designers were able to move the backrest lever to the front, then a follow-up pressurized test and/or gap analysis is recommended to ensure all crew members can access a lever in the front.

## **Reference**

Chaffin, D.B. and Andersson, G.B.J., *Occupational Biomechanics*, Wiley & Sons, New York, NY, 1994.

## Appendix A

### Maximum Static Exertion Data per Subject per Trial

*SUBJECT:* 1                                      *Sex:* Male                                      *Condition:* Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	35.53	17.33
	31.07	18.55
		25.28
		18.67
AVG	<u>33.30</u>	<u>19.96</u>
Ratio	0.60	

*SUBJECT:* 2                                      *Sex:* Female                                      *Condition:* Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	5.05	2.46
	5.13	5.92
	4.49	2.55
	3.70	5.61
AVG	<u>4.59</u>	<u>4.14</u>
Ratio	0.90	

*SUBJECT:* 3                                      *Sex:* Male                                      *Condition:* Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	35.29	24.77
	64.77	26.41
	46.07	28.96
	42.77	29.69
AVG	<u>47.22</u>	<u>27.46</u>
Ratio	0.58	

*SUBJECT:*  
6

*Sex:*  
Male

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	34.06	31.54
	31.49	29.85
	32.18	35.92
		27.68
AVG	<u>32.58</u>	<u>31.25</u>
Ratio	0.96	

*SUBJECT:*  
7

*Sex:*  
Female

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	9.92	7.54
	8.49	6.32
	8.35	6.04
	6.95	7.16
AVG	<u>8.43</u>	<u>6.77</u>
Ratio	0.80	

*SUBJECT:*  
8

*Sex:*  
Female

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	38.44	15.52
	41.64	27.00
	41.61	29.48
	40.84	28.81
AVG	<u>40.63</u>	<u>25.20</u>
Ratio	0.62	

*SUBJECT:*  
9

*Sex:*  
Male

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	23.89	10.62
	19.65	7.00
	15.19	7.76
		9.72
AVG	<u>19.58</u>	<u>8.78</u>
Ratio	0.45	

*SUBJECT:*  
10

*Sex:*  
Female

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	7.64	3.35
	6.82	
	6.28	
	4.30	
AVG	<u>6.26</u>	<u>3.35</u>
Ratio	0.53	

*SUBJECT:*  
11

*Sex:*  
Male

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	30.64	27.69
	33.68	30.29
	45.90	25.56
	40.06	22.25
AVG	<u>37.57</u>	<u>26.45</u>
Ratio	0.70	

*SUBJECT:*  
12

*Sex:*  
Female

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	48.71	11.91
	40.14	15.08
	46.18	24.33
	35.65	19.39
AVG	<u>42.67</u>	<u>17.68</u>
Ratio	0.41	

*SUBJECT:*  
5a

*Sex:*  
Female

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	7.35	3.786
	5.01	3.92
	7.33	3.79
	6.78	4.78
AVG	<u>6.62</u>	<u>4.07</u>
Ratio	0.61	

*SUBJECT:*  
5b

*Sex:*  
Female

*Condition:*  
Unpressurized

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	11.99	4.801
	9.18	5.39
	10.31	4.79
	7.66	3.34
AVG	<u>9.78</u>	<u>4.58</u>
Ratio	0.47	

*SUBJECT:*  
*5b*

*Sex:*  
*Female*

*Condition:*  
*Pressurized*

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	3.91	
	4.54	
	3.78	
	2.77	
AVG	<hr/> 3.75 <hr/>	

*SUBJECT:*  
*4a*

*Sex:*  
*Male*

*Condition:*  
*Unpressurized*

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	38.22	22.80
	47.19	15.59
	44.67	13.82
	39.64	13.25
AVG	<hr/> 42.43 <hr/>	<hr/> 16.36 <hr/>
Ratio	0.39	

*SUBJECT:*  
*4b*

*Sex:*  
*Male*

*Condition:*  
*Unpressurized*

	Maximum Inertia Lever Force (lb)	Maximum Backseat Lever Force (lb)
	70.05	9.68
	70.03	12.48
	63.40	19.31
		14.50
AVG	<hr/> 67.83 <hr/>	<hr/> 13.99 <hr/>
Ratio	0.21	

*SUBJECT:*  
*4b*

*Sex:*  
*Male*

*Condition:*  
*Pressurized*

Maximum Inertia  
Lever Force (lb)

Maximum Backseat  
Lever Force (lb)

30.138

30.30

27.15

AVG

---

29.20

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13. ABSTRACT (Maximum 200 words) In 1999, a Shuttle crew member was unable to operate the backrest lever for the lightweight seat in microgravity. It is essential that crew members can adjust this backrest lever, which is tilted forward during launch and then moved backward upon reaching orbit. This adjustment is needed to cushion the crew members during an inadvertent crash landing situation. JSC's Anthropometry and Biomechanics Facility (ABF) performed an evaluation of the seat controls and provided recommendations on whether the seat lever positions and operations should be modified. The original Shuttle seats were replaced with new lightweight seats whose controls were moved, with one control at the front and the other at the back. The ABF designed a 12-person experiment to investigate the amount of pull force exerted by suited subjects, when controls were placed in the front and back of the lightweight seat. Each subject was asked to perform the pull test at least three times for each combination of lever position and suit pressure conditions. The results showed that, in general, the subjects were able to pull on the lever at the back position with only about half the amount of force that they were able to exert on the lever at the front position. In addition, the results also showed that subjects wearing the pressurized suit were unable to reach the seat lever when it was located at the back. The pull forces on the front lever diminished about 50% when subjects wore pressurized suits. Based on these results from this study, it was recommended that the levers should not be located in the back position. Further investigation is needed to determine whether the levers at the front of the seat could be modified or adjusted to increase the leverage for crew members wearing pressurized launch/escape suits.				
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1